

On origin of 1/f noise in manganites: memoryless transport against mysterious slow fluctuators

Yu. E. Kuzovlev*

Donetsk Physics and Technology Institute, 83114 Donetsk, Ukraine

An alternative explanation of 1/f-noise in manganites is suggested and discussed.

PACS numbers: 05.40.-a, 71.27.+a

1. Introduction.

The so-called perovskite manganites, or colossal magneto-resistance manganites [1, 2], are materials known as “1/f-noise champions”. For proper references see works [3–5], since just their extremely interesting experimental results stimulated my present communication. Namely, first, observation of very high level of 1/f noise in good bulk crystals (instead of thin films as usually). Second, very weak dependence of this noise (expressed in standard relative units via $S_R(f)/R^2$) on temperature in wide from the room one down to 79° K. At 79° K transition to strongly non-ohmic regime was found and attracted most authors’ “theoretical interest” in [3–5].

In my opinion, however, discussion of the wide Ohmic region may be much more useful for understanding nature of 1/f-noise. Below I will try to suggest a principal alternative to the hypotheses seemingly accepted by authors of [3–5].

2. Experimental data.

In the mentioned temperature range, resistance of the $L = 0.3$ mm long part of rectangular crystal with cross-section $A = 2 \times 3$ mm² changed between $R(300^\circ\text{K}) \approx 2$ Ohm and $R(80^\circ\text{K}) \approx 200$ Ohm [5]. At that, the power spectral density (PSD) of relative resistance fluctuations was practically independent on temperature,

$$\frac{S_V(f)}{V^2} = \frac{S_R(f)}{R^2} \approx \frac{4 \cdot 10^{-11}}{f} \quad (1)$$

3. Standard interpretation.

Most popular interpretation of 1/f-noise in solids relates it to some hypothetical thermally activated “fluctuators” with wide enough variety of activation energies [6, 7]. Under suitable parameters, this model can well reproduce both frequency and temperature dependencies of 1/f-type PSDs. But it never helped to indicate physical nature of “fluctuators”, thus prompting that they hardly exist in literal sense.

If, nevertheless, they really take place and, - as authors of [5] do allude, - represent more or less local structural rearrangements or switchings between coexisting phases, then we can write

$$\frac{S_V(f)}{V^2} = \frac{S_R(f)}{R^2} \sim \frac{1}{f N \ln(f_2/f_1)}, \quad (2)$$

where f_2 and f_1 are upper and lower 1/f-noise frequencies under measurements, and N is number of fluctuators in the observed volume $\Omega \approx LA$ (though may be $\Omega \sim L^3$ is more reasonable estimate). Comparison of (2) with (1) gives $N \sim 10^9$, and thus typical fluctuator takes in a volume with linear size $l \sim (\Omega/N)^{1/3} \sim 10^{-4}$ cm (if not $l \sim (L^3/N)^{1/3} \sim 2 \cdot 10^{-5}$ cm).

Likely, that are too large space regions to be characterized by so small activation energy barriers as $\sim k_B T \ln(f_2/f)$.

4. Alternative interpretation.

The possibility of coexistence of different phases in CMR manganites means that they are materials with “strongly correlated electrons” (see e.g. [1, 2] and references in [3–5]). “Strong correlations” (resulting, in particular, from Coulomb interactions and Coulomb blockade) may strongly decrease effective number of free charge carriers, i.e. simultaneously and independently movable ones (see e.g. example in [8]).

The remaining free carriers can be considered from viewpoint of another popular empirical model [9, 10] where

$$\frac{S_V(f)}{V^2} = \frac{S_R(f)}{R^2} \approx \frac{\alpha}{f N}, \quad (3)$$

with N being number of carriers in the observed volume, and α called “Hooge constant”. In usual crystal materials, when inelastic lattice (phonon) scattering dominates, $10^{-3} \lesssim \alpha \lesssim 10^{-1}$ [9–11]. Taking $\alpha = 10^{-2}$ for rough comparison of (3) and (1), we have again $N \sim 10^9$, but now with movable carriers in the role of “fluctuators”.

The corresponding characteristic length $l \sim (\Omega/N)^{1/3} \sim 10^{-4}$ cm seems, of course, very large. But, nevertheless, it is well compatible with the experimental conductivity,

$$\sigma = L/RA \approx 2.5 \cdot 10^{-3} \div 2.5 \cdot 10^{-1} \text{ Ohm}^{-1} \cdot \text{cm}^{-1},$$

if we assume that this conductivity is determined by inelastic jumps of carriers between relatively isolated spatial regions (“grains”) with volumes $\sim \Omega$.

Indeed, if elementary transition through a boundary between neighbor regions take a time $\sim \tau$, then maximal (saturation) current per one elementary boundary (with area $\sim l^2$) is on order of $J_{max} \sim e/\tau$ (the saturation just reflects the “strong correlations”). Then in

ohmic (low-voltage) regime the current must be

$$J \approx \frac{eU}{k_B T} J_{max} = \frac{e^2 U}{k_B T \tau},$$

where $U \approx IV/L$ is potential drop across the boundary. This means, evidently, that ohmic conductivity of such medium obeys estimate

$$\sigma \sim \frac{e^2}{k_B T \tau l} \lesssim \frac{e^2}{\hbar l} \sim 1 \text{ Ohm}^{-1} \cdot \text{cm}^{-1}$$

(due to natural restriction $\tau \gtrsim \hbar/k_B T$), which agrees with above experimental values.

5. Free carriers as 1/f-type fluctuators.

Specific characteristics of the “grains” are not principally important for low-frequency electric noise produced by the free (movable) carriers. The only principal thing is that the system constantly forgets history of their jumps.

If it is so, then possible fluctuations in amount of charge transport grow with time like most probable amount do, i.e. nearly proportionally to time (for, figuratively speaking, the system without memory can not distinguish between a “norm” of transport events and their “excess” or “deficiency”).

This just means that rate of transport (PSD of transport noise and the system’s conductance) undergoes scaleless 1/f-type fluctuations (so that time-averaged rate varies from one experiment to another). In terms of individual carriers, their diffusivities/mobilities have no certain value but fluctuate with 1/f-type spectrum.

First statistical theory of these fluctuations was published in [12, 13] presenting, in particular, clear explanation of the “Hooge constant” (see also [8, 11, 14–16] and references therein).

6. Conclusion.

The essence of the appointed view is that 1/f-noise comes not from hierarchy of long memory times but, in opposite, from absence of long memory at all. Such 1/f-noise is trivially compatible with finiteness of “residence times” of particular carriers in a sample (as well as finiteness of their life-times under generation-recombination processes, etc.). Thus we eliminate both the corresponding farfetched questions [7, 10] and need in mysterious slow “fluctuators” inside the sample.

Unfortunately, inertia of scientific prejudices is so strong that these simple ideas were not assimilate during 30 years after the works [11–13].

The matter is that transport processes traditionally are thought as “stochastic” ones, in the sense of probability theory, with *a priori* certain (let numerically unknown) rates. But in reality they obey the Hamiltonian dynamics which, - as honest considerations do show [8, 14, 16–21], - always predicts 1/f fluctuations in transport rates. Thus, fundamental quantitative theory of 1/f-noise in manganites requires, first of all, a good Hamiltonian model of charge transport in these materials.

* kuzovlev@fti.dn.ua

- [1] Physics of manganites. Editors T.A. Kaplan and S.D. Mahanti. Kluwer, 2002.
- [2] E. Dagotto. Nanoscale phase separation and colossal magnetoresistance. Springer-Verlag, 2002.
- [3] B. Dolgin. “Transport properties and noise in CMR manganites”. Thesis. Ben-Gurion Univ., 2010.
- [4] X.D. Wua, B. Dolgin, G. Jung, et al., Appl. Phys. Lett. **90**, 242110 (2007).
- [5] M. Belogolovskii, G. Jung, V. Markovich, et al. arXiv: 1103.0961.
- [6] P. Dutta and P.M. Horn, Rev. Mod. Phys., **53**, 497 (1981).
- [7] M.B. Weissman, Rev. Mod. Phys., **60**, 537 (1988).
- [8] Yu. E. Kuzovlev, Yu. V. Medvedev, and A. M. Grishin, JETP Letters **72** (2000) 574; Phys. Solid State **44**, No. 5 (2002) 843.
- [9] F.N. Hooge, T.G.M. Kleinpenning, and L.K.J. Vandamme, Rep. Progr. Phys. **44**, 479 (1981).
- [10] F.N. Hooge, IEEE Trans. El. Dev. **41**, No.11, 1926 (1994).
- [11] G.N. Bochkov and Yu. E. Kuzovlev, Sov.Phys.-Uspekhi **26**, 829 (1983).
- [12] Yu. E. Kuzovlev and G.N. Bochkov, Pis'ma v ZhTF **8**, No.20, 1260 (1982) [in Russian; transl. to English in Sov. Tech. Phys. Lett. (1982)]; “On the nature and statistical characteristics of 1/f-noise”, Preprint No.157, NIRFI, Gorkii, USSR, 1982 (in Russian).
- [13] Yu. E. Kuzovlev and G.N. Bochkov, Radiophysics and Quantum Electronics **26**, No. 3, 228 (1983); **27**, No.9 (1984).
- [14] Yu. E. Kuzovlev, arXiv: cond-mat/9903350.
- [15] Yu. E. Kuzovlev, arXiv: 1008.4376.
- [16] Yu. E. Kuzovlev, arXiv: 1107.3240, 1110.2502.
- [17] Yu. E. Kuzovlev, Sov.Phys.-JETP **67** (12), 2469 (1988); arXiv: 0907.3475. Available online: www.jetp.ac.ru/cgi-bin/dn/e_067_12_2469.pdf
- [18] Yu. E. Kuzovlev, Sov.Phys.-JETP **84** (6), 1138 (1997).
- [19] Yu. E. Kuzovlev, arXiv: cond-mat/0609515.
- [20] Yu. E. Kuzovlev, arXiv: 0802.0288.
- [21] Yu. E. Kuzovlev, Theoretical and Mathematical Physics, **160** (3), 1300-1314 (Sep. 2009) {DOI:10.1007/s11232-009-0117-0}; arXiv: 0908.0274.